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Seasonal nitrogen fixation in the sediment of an Amazonian lake impacted by bauxite tailings (Batata Lake-Pará)

by

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Abstract

Batata Lake is an Amazonian clear water lake that undergoes large seasonal fluctuations in water level. For a period of 10 years (1979-1989), the northern end of the lake received a total of 50,000 m^3d^{-1} of bauxite tailings. As a consequence spelling aproximately 30 % of its sediments are covered by tailings. The principal goal of this research was to estimate rates of nitrogen fixation in the impacted and non-impacted sediment in the different hydroperiods that occur in this ecosystem (drawdown, drying, filling and flooding). Nitrogen fixation was estimated using the acetylene reduction method. The highest rates of nitrogen fixation were observed to occur during the drying period and appear to be directly related to an increase in primary production by phytoplankton. Decreased rates of nitrogen fixation occurred during the hydroperiods of filling, flooding and drawdown with the greatest reductions occuring in the impacted area of the lake. In the impacted area of the lake, bauxite tailings have reduced primary production in the water column, decreased labile authoctonous carbon availability to heterotrophic bacteria in the sediments, and decreased nitrogen fixing activity of organisms present the sediments.

Keywords: **Bauxite tailings, Amazonian lake, nitrogen cycle, nitrogen fixation, sediment**.

Resumo

O lago Batata é um lago de águas claras, submetido a flutuação sazonal do nível d'água. Durante 10 anos (1979-1989), a região norte do lago recebeu um total de 50.000 m^3 d^{-1} de rejeito de bauxita. Como consequência, cerca de 30% da área do lago foi impactado por rejeito de bauxita. O principal objetivo desta pesquisa foi estimar as taxas de fixação biológica de nitrogênio no sedimento da área impactada e natural durante vários períodos do ciclo hidrológico (vazante, seca, enchente e cheia). A fixação biológica de nitrogênio foi estimada usando o método da redução de acetino. As maiores taxas de fixação de nitrogênio foram observadas durante o período de seca e parecem estar diretamente relacionadas ao aumento da produção primária fitoplanctônica. Redução das taxas de fixação biológicas ocorreram durante o período de enchente, cheia e vazante, com grande redução sendo observada na área impactada do lago.

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Na área impactada, o rejeito de bauxita reduz a produção primária fitoplanctônica na coluna d'água, diminuindo a disponibilidade de carbono lábil autóctone para bactérias heterotrofas do sedimento, a qual promove a redução da atividade dos organismos fixadores de nitrogênio presentes no sedimento.

Introduction

The aquatic and terrestrial ecosystems located in the central part of the Amazon region are avowedly poor in nutrients (SIOLI 1984). Yet, despite the scarcity of nutrients, Amazonian aquatic ecosystems are very productive due to high nutrient recycling rates (JUNK et al. 1989).

Nitrogen is a critical nutrient in aquatic ecosystems because it often limits primary productivity (HUTCHINSON 1957; WETZEL 1972; HORNE & GOLDMANN 1994). This is certainly also true of Amazonian ecosystems. MELACK & FISCHER (1988) showed that lack of nitrogen was severely limiting to algal growth in Amazonian floodplain, directly decreasing primary productivity of the system they studied. In this paper, rates of nitrogen fixation are estimated for sediments covered by bauxite tailings and naturally sedimented areas of Batata Lake as large seasonal fluctuations occur in water level.

Study area

Batata Lake (Pará-Brazil), is a clear water lake on the west bank of the Trombetas River (1°30'S e 56°20'W; Fig. 1). For ten years this lake received, 50,000 m^3d^{-1} of bauxite tailings containing ore residues and 7 to 9 % clays particles of less than 50 μm in size. This mining effluent covered aproximately 30 % of the total lake sediments at the northern end of the lake. Batata Lake is also subject to large fluctuations in hydroperiod. During the course of this research, the lake fluctuated approximately 8.5 meters in dept exhibiting periods of filling (rising water level); flooding (highest water level); drawsown (water level decreasing), and drying (lowest water level).

Material and methods

Sediment samples were collected at two stations in Lake Batata: a) in the northern area impacted by bauxite tailings, and b) in the southern non-impacted or natural area of the lake. Samples were collected during filling (7.5 meters depth - March), flooding (9.5 meters depth - June), drawdown (6.5 meters - September) and drying (1.0 meter depth - December) in 1994 with a hand held coring device. At each station, 10 cores were collected with a corer sampler as proposed by AMBÜHL & BÜHRER (1975). The top three cm of each core were carefully removed, pooled, throughly homogenized, and placed in 100 ml glass bottles capped with serum stoppers. Bottles were kept cool and transported to the laboratory where they were evacuated at 75 ml min^{-1} pure nitrogen for 4 min to maintaining anaerobic conditions.

Rates of nitrogen fixation in the sediment samples were estimulated using the acetylene reduction method (HARDY et al. 1968). Each pooled sediment sample was analysed in triplicate, accompanied by a control sample. Acethylene was added to the headspace to an initial concentration of 15 % (v:v) except for controls that did not have acetylene added to them. Samples were incubated in the dark at 26 °C to

measure the diazotrophic activity of heterotrophic organisms in the sediments. After 2.0 h of incubation, 3.5 ml of gas were withdrawn form the headspace of each bottle with a gas-tight syringe, transfered to 7 ml Vacuntainers, and analysed within 2 weeks after sampling.

Ethylene concentrations were determined in a Varian 3400 gas liquid chromatograph using a flame ionization detector (200 °C), a Porapak N column (60 °C), and an injector temperature of 100 °C. The standard ratio of 3:1 for ethylene reduced to nitrogen reduced was used to calculete absolute rates of nitrogen fixed by the sediments (HARDY op. cit.).

Temperature and oxygen concentrations of the water-sediment interface were measured in the field using a Model DO-11P TAO Oximeter. Total organic carbon (by the dichromate oxidation method) concentrations of the sediment were performed according to GOLTERMAN et al. (1978).

Results and discussion

The large fluctuation in water level that occur in Amazonian ecosystems is a basic determinant of ecological structure and function in the Amazon basin. This phenomenon is discussed by JUNK et al. (1989) and is commonly reffered to as flood pulse. In this paper we show that variations in water level of 1.5 to 9.5 m over our collection stations directly influence nitrogen fixation in the sediments of the non-impacted area of Batata Lake. An ANOVA analyses showed that the nitrogen fixation rates during drying period was significantly greater ($\alpha = 0.05$) than other periods of the hidrocycle (Fig. 2). During drying periods, observed nitrogen fixation rates are approximately 7 times greater for non-impacted sediments (0.40 nmol g^{-1} $D.W.h^{-1}$) compared to impacted sediments (0.061 nmol g^{-1} $D.W.h^{-1}$). The non-impacted area present significantly higher values (ANOVA, $\alpha = 0.05$) than the impacted area, during the flooding, drawdown and drying. Nitrogen fixation rates in impacted sediments does not vary significantly (ANOVA, $\alpha = 0.05$) during flooding, drawdown or drying periods, varying only from 0.034 to 0.05 nmol g^{-1} $D.W.h^{-1}$ during these periods (Fig. 2). During filling, nitrogen fixation is almost not detectable in the sediments of both impacted and non-impacted areas of the lake.

HUZSAR (1996), who studied the phytoplanktonic populations of Batata Lake, reported that phytoplancton communities increase during the drying period. It is during this portion of the hydroperiod that Batata Lake is not connected with the igapo forest (flooded forest). As a consequence, sedimentation of the organic carbon from the phytoplancton communities in the water column is most likely promoted as lake water levels and currents decrease during the drying period (FERRÃO-FILHO & ESTEVES 1994). However, this organic carbon, whose source is the phytoplancton, is mainly labile carbon, i.e. carbon that can be readily assimilated by heterotrophic bacteria including nitrogen fixers (WETZEL et al. 1972; KNOWLES 1982). During the drying hydroperiod, we observed an increase in phytoplankton occuring in the non-impacted sediments, a decrease in organic carbon to these same sediment (6.0 %), and a peak in nitrogen fixation suggesting that heterotrophs are rapidly utilizing this carbon as it becomes available to them (Table 1 and Fig. 2). In contrast, we observed that organic carbon concentrations (1.9 %) were greatest in the sediments during the same period suggesting that the altered sediments do not support a high population of organic carbon utilizing heterotrophs (Table 1).

Deposition of greater amounts of carbon to the non-impacted sediments as well as decreased rates of nitrogen fixation are found during filling, flooding and drawdown periods suggesting low utilization of labile carbon by microorganisms during these

portions of the hydroperiod. Extensive areas of forest adjacent and upstreams of Batata Lake area inundated during periods of filling and flood. During these periods considerable allochthonous carbon enters Lake Batata as refractory carbon, i.e. carbon in the form of cellulose, lignin and pectin, that is not available for rapid utilization by bacterial heterotrophs. This carbon is observed to increase in non-impacted sediments at high rates during filling (6.7 %), flooding (9.4 %), and drawdown (7.2 %).

The flood pulse affecting Batata Lake certainly changes the nitrogen fixing activity of the sediments. The low values for nitrogen fixation observed during filling, flooding and drawdown for both non-impacted and impacted sediments are probably related to rapid changes in water volume during these periods which effect changes in the phytoplancton populations (FERRÃO-FILHO & ESTEVES 1994). This decrease in rate of nitrogen fixation is most notable for the impacted areas of the lake. Bauxite tailings in suspension in the water column have at least two deleterious effects on this ecosystem. Tailings cloud in the water column directly reducing primary phytoplanktonic production (ROLAND et al. 1996) by decreasing photosynthetically active radiation available to photosynthetic organisms and thus the availability of labile carbon for heterotrophs such as nitrogen fixers. Secondly, the bauxite tailings covering the sediments modify abiotic conditions in the sediments by limiting nitrogen transfer to the sediments. Total organic carbon in the sediments covered with tailings ranges from about 17 to 32 % of the organic carbon present in natural sediments in the lake (Table 1). Oxygen concentrations at the sediment-water interface were always less for the non-impacted sediments than for the impacted sediments suggesting that the natural sediments could support larger populations of oxygen utilizing organisms than in the impacted areas.

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Table 1: Organic carbon concentrations of the sediment and temperature and oxygen concentration of the sediment-water interface from the natural and impacted areas of Batata Lake during the year of 1994.

Hydroperiods	Carbon % D.W.	T °C	Oxygen mg/l	Oxygen % sat.
Filling (March)				
Impacted area	1.8	29.4	3.5	46.0
Natural area	6.7	29.7	0.85	11.0
Flooding (July)				
Impacted area	1.6	26.8	4.0	49
Natural area	9.4	26.4	3.0	45
Drawdown (September)				
Impacted area	1.3	30.9	1.26	17
Natural area	7.1	29.1	0.26	3
Drying (December)				
Impacted area	1.9	28.0	8.15	105
Natural area	6.0	28.8	7.68	102

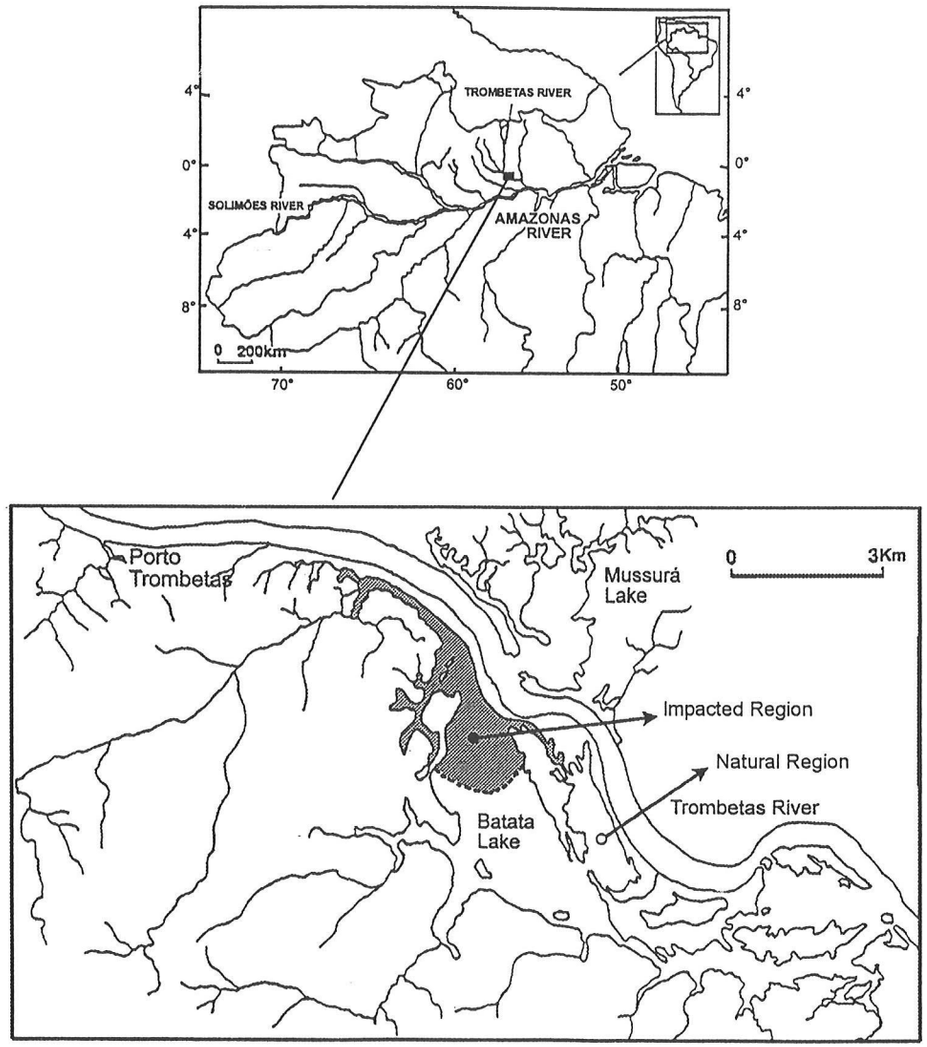

Fig. 1:
Location of the study area and the sampling stations.

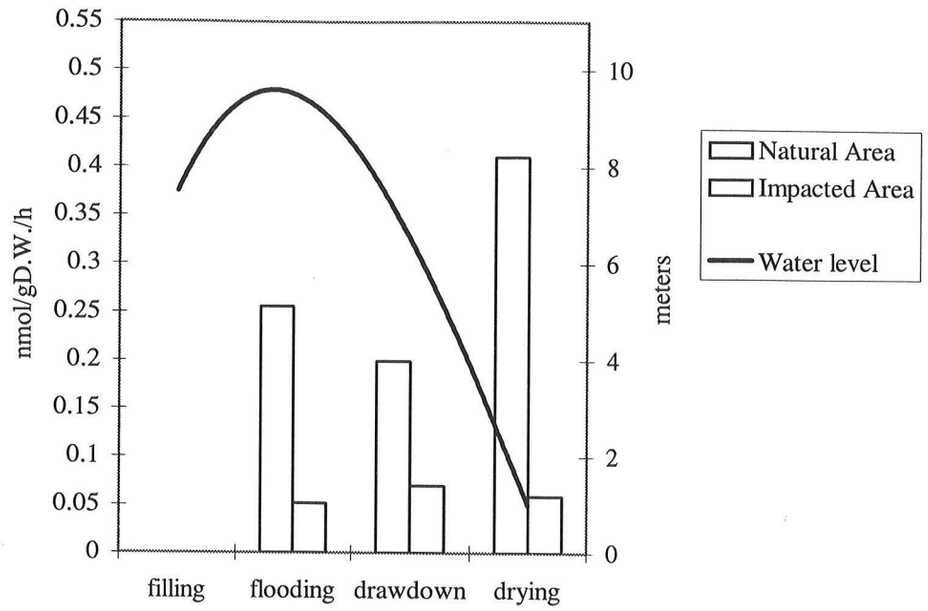

Fig. 2:
Values form the nitrogen fixation rates in the sediment from the natural and impacted regions of Batata Lake in 1994.